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ULTRASONIC SENSORS FOR IN SITU MONITORING OF PHYSICAL PROPERTIES

TECHNOLOGY NEED

An estimate of 381,000 m³ of radioactive waste with a radioactive decay of 1.1 billion Ci are stored in high-level waste tanks at Hanford, Savannah River, Idaho National Engineering Laboratory (INEL), and West Valley facilities. These nuclear wastes have created one of the most complex waste management and cleanup problems facing the United States. Release of radioactive materials to the environment from underground waste tanks requires immediate actions of cleanup and waste retrieval. Hydraulic mobilization with the use of mixer pumps will be the process used to retrieve waste slurries and salt cake from storage tanks. To ensure that transport lines in the hydraulic system will not plug, the physical properties of the slurries must be monitored. Characterization of a slurry flow needs reliable measurements of slurry density, mass flow, viscosity, and volume percent solids. The measurements are preferably made with on-line, nonintrusive sensors that can provide continuous real-time monitoring.

TECHNOLOGY DESCRIPTION

Nonintrusive ultrasonic techniques, which have already been widely applied to industrial process controls, are the base technology for this proposed sensor development. Two ultrasonic sensors will be developed and field demonstrated in this project. One is a nonintrusive ultrasonic viscometer for on-line fluid viscosity measurement, and the other is an ultrasonic imaging system for monitoring the volume percent of solids in waste transport lines. Both sensors will be applied to in situ measurements, thus, the sensors will be designed to adapt the process conditions that are corrosive and radioactive. The proposed design of the sensor configuration will consist of two circular arrays of ultrasonic transducers, shear and longitudinal. Each sensor array uses special purpose wedges for transducer mounting. The wedges provide transducer isolation from the process stream and self-calibration capability. The design and measurement principles of the two sensors are described below.

Ultrasonic Viscometer

An ultrasonic viscometer was developed at Argonne National Laboratory (ANL) and was the recipient of an R & D 100 award in 1994. The basic design consists of a pair of ultrasonic transducers mounted on the special purpose wedges. The wedge has a design of two reflection surfaces. One surface is in contact with the fluid being monitored, and the other is exposed to the air. Reflected signals from the two surfaces are measured. The signal amplitudes

(phase changes are negligible) are used to calculate the reflection coefficient of the fluid. Signals reflected from the air side of the wedge represent the total reflection, and thus can be used as reference signals to provide continuous on-line calibration. The Ultrasonic reflection coefficient, R , can be related to ultrasonic impedances of the fluid (Z) and wedge (Z_w) by the relationship of:

$$R = (Z - Z_w) / (Z + Z_w).$$

Since Z_w is a wedge constant, the reflection coefficient measurement gives a direct measure of the fluid impedance. Ultrasonic impedance depends on the type of ultrasonic wave utilized. For the present applications, we consider only acoustic and shear impedances, the former relates to longitudinal mode and the latter corresponds to shear mode. Shear impedance of fluid is given by the square root of the product of fluid density and viscosity. Hence, measuring shear impedance alone does not give a direct measurement of fluid viscosity; another independent measurement is needed to determine the fluid density. This can be achieved by measuring the acoustic impedance of the fluid, which is defined as the product of fluid density and sound velocity. Therefore, the basic design of the viscometer requires both longitudinal and shear wave transducers. The Pulse-echo method is the measurement technique. Longitudinal-wave operation measures sound velocity (V) and acoustic impedance (Z_L) of the fluid, from which fluid density ($\rho = Z_L/V$) is determined. Because fluids do not support shear motion, only the fluid shear impedance (Z_s) can be measured. However, the shear viscosity (η) can be deduced from


$$\eta = (Z_s)^2 / \rho \omega,$$

where ω is the angular frequency. The performance of the ANL viscometer has been evaluated, and at present, the viscometer is applicable only to high viscosities. The design must be modified to allow application to low viscosities (less than 30 cP). This modification is to be the focus of development in the proposed project.

Sensor for Volume Percent Solids

On-line measurement of solids concentration in a solid suspension is very difficult. Resolving particle size distribution is even more complex. Ultrasonic methods have been commonly used for on-line monitoring of solid/liquid flows. At present, ultrasonic flowmeters based on the Doppler or cross-correlation effects have been well developed and applied to flow monitoring. But reliable methods to measure solid concentration have not been established. Some empirical relationships that relate ultrasonic velocity and attenuation to solid concentration have been reported.

Attenuation of ultrasonic waves propagating in homogeneous coal slurries of concentration up to 30% by volume was measured at ANL and the result exhibits a nonlinear dependence on solids concentration. In principle, ultrasonic attenuation is affected by thermal, viscosity, and scattering effects. Therefore, attenuation measurement tends to over-estimate the percent solid



concentration. It has also been observed that the presence of solid particles, particularly of high concentration, may focus ultrasonic waves in the forward direction, thus introducing error in attenuation measurement. Perhaps a better approach is to measure the scattering patterns and establish a correlation between scattering patterns and solid concentrations. Theoretical studies at ANL have shown some of the pattern variation due to increases of solid particles in the fluid. Therefore, we propose to develop a solids-concentration sensor based on measurements of ultrasonic wave scattering pattern. The sensor will consist of a circular array of longitudinal transducers that will send out ultrasonic pulses and receive the scattered waves. An inverse algorithm will be developed to determine volume percent solids and, potentially, particle distribution in the sensing volume. A preliminary study on ultrasonic flow imaging has demonstrated the feasibility of this concept.



BENEFITS

Treatment of waste at waste processing facilities requires the transfer of slurries between storage tanks. The slurries are typically a complex, multi-phase, and highly stratified mixture of saltcake, sludge, and supernatant. During transfer, transport lines may be plugged because of excessive solids in the slurry. The estimated cost to replace a plugged transport line at Hanford is \$47 million. To avoid the transport lines being plugged, the slurry flow must be maintained in the turbulent flow region which requires a Reynold number less than 22,000, a specific gravity less than 1.5, a viscosity less than 30 cP, and a volume percent solids less than 30. Therefore, in situ measurements of slurry density, viscosity, and volume percent solids will ensure the safe and continuous operation of waste transfer. Major benefits to the overall waste retrieval and cleanup are (1) maintaining safe operation, (2) avoiding costs due to line plugging, and (3) providing waste accountability.



COLLABORATION/TECHNOLOGY TRANSFER

The project will produce two practical on-line flow monitoring sensors that have wide applications in many industrial processes, especially the processes involving solid suspension such as coal and paper/pulp slurries. The ultrasonic viscometer is in the process of technology transfer to the Brookfield Engineering Laboratories, Inc. (BEL), Stoughton, Massachusetts, and an industrial prototype will be built and demonstrated in early 1996. The sensor for volume percent solids measurement will be transferred to the flow-instrument industry at its completion. The sensor can be further developed into a real-time flow imaging system, which will increase its market value and industrial application.

ACCOMPLISHMENTS

Work Element A: Evaluation of transducer wedge design:

- Completed a theoretical model for wedge-material evaluation.
- Completed the wedge design for the laboratory prototype viscometer.

TTP INFORMATION

Ultrasonic Sensors For In Situ Monitoring of Physical Properties technology development activities are funded under the following Technical Task Plan (TTP):

TTP No. CH26C217 "Ultrasonic Sensors For In Situ Monitoring of Physical Properties"

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